(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
16 May 2002 (16.05.2002)

PCT

(10) International Publication Number
WO 02/38319 A2

(51) International Patent Classification[7]: B23K

(21) International Application Number: PCT/US01/47333

(22) International Filing Date: 13 November 2001 (13.11.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/248,446 13 November 2000 (13.11.2000) US

(71) Applicants and
(72) Inventors: **KUNOWSKI, H., Jon** [US/US]; 5124 W. Saguaro Park Lane, Glendale, AZ 85310-2914 (US). **SIMACEK, Dalibor** [AU/US]; 4415 E. Via Montoya Drive, Phoenix, AZ 85050 (US). **BINDL, Ronald, H.** [US/US]; 6394 W. Donald Drive, Glendale, AZ 85310 (US).

(74) Agent: **ONEY, Richard, E.**; Fennemore Craig, 3003 North Central, Suite 2600, Phoenix, AZ 85012-2913 (US).

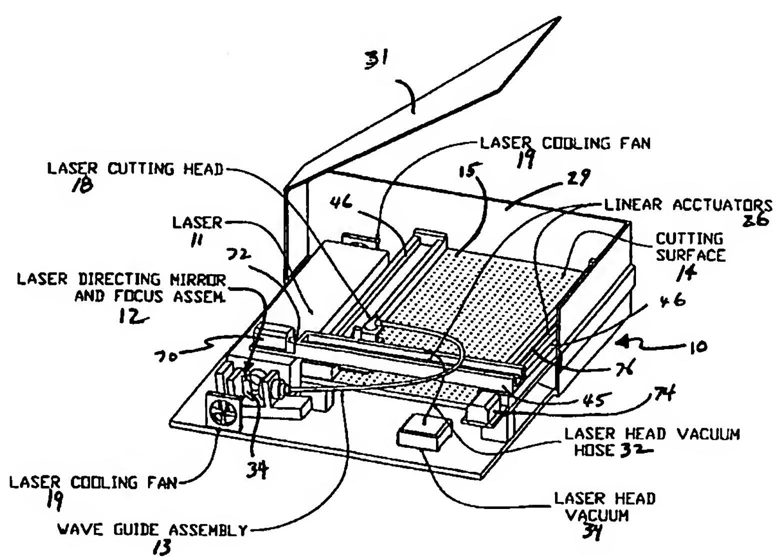
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: PORTABLE LASER PROCESSING SYSTEM



CASE CUT AWAY FOR CLARITY

(57) **Abstract:** A laser processing system for cutting sheet work material includes a laser generator for generating a laser beam for cutting the work material, a work surface for supporting the work material, a cutting head located above the work surface for projecting the laser beam toward the work surface, a beam delivery system for coupling the laser beam to the cutting head and a drive system for moving the cutting head along a selected path over the work surface. The beam delivery system includes a flexible waveguide covered with a steel monocoil protective flexible sheath. The work surface is covered by a heat-absorbing coating. The laser processing system is enclosed in a lightweight case, such as a case comprising molded plastic.

WO 02/38319 A2

PORTABLE LASER PROCESSING SYSTEM

RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application No. 60/248,446, filed November 13, 2000, entitled "Portable Laser Processing System," which is incorporated herein by reference.

BACKGROUND

The present invention relates to laser cutting systems. More particularly, it relates to a laser processing system suitable for cutting two dimensional patterns or parts from thin sheet material or for engraving sheet material, such as plastic or metal sheet material. The laser processing system of the present invention includes an optical waveguide beam delivery assembly and is portable, relatively inexpensive to manufacture and easy to use and maintain.

Laser cutters for sheet material are known for cutting parts from thin sheet material wherein the work material is supported on a work surface, a laser beam is projected onto the work material from a cutting head located above the work surface, and the cutting head and work material supported on the support surface are moved relative to one another in two coordinate directions to cause the beam to trace and cut a desired two dimensional line on the sheet material. Examples of such laser cutting systems are shown in U.S. Pat. No. 4,675,497 to Pearl, et al. and U.S. Pat. No. 5,910,260 to Gerber.

These previously known laser cutting systems are relatively large and heavy and are expensive to manufacture. These systems utilize an "open air" laser beam directed by a system of mirrors. For safety reasons, these systems include a case that encloses the entire system in order to contain the laser beam and protect the user from accidental exposure to the beam. To perform this function, the case is made of a relatively heavy material that cannot be cut by the beam, such as steel. Such a case is relatively costly to manufacture.

In addition, the moving parts of many previous systems are quite massive, so that considerable inertias are associated with the drives for moving the cutting head and the work material relative to one another in each of the two coordinate directions. The resulting difficulty in accelerating and decelerating the relatively moving parts has in general made it necessary to operate the cutters at relatively slow speeds in order to cut with reasonable accuracy, especially in cases where the parts to be cut from the work

material are of complex shapes requiring the beam to be stopped and restarted, or at least slowed, at corner points or other points at which notches, holes, or other small features of intricate nature are to be cut. Such cutters, capable of cutting at reasonably acceptable speed and accuracy, have also been costly to manufacturer.

Moreover, in previously known cutting systems, the mirror systems for delivering the laser beam to the cutting head suffer from a number of drawbacks. In such systems that use an "open air" beam, the mirrors are also exposed to the open air and particulate matter in the air, and consequently require cleaning to assure proper operation. In addition, with such systems that utilize movement of the cutting head, the distance that the laser beam must travel from the laser generator output to the cutting head will vary as the cutting head moves over the work surface. This variation results in a variation in the diameter of the beam delivered to the cutting head, which results in a variation of the beam power delivered to the surface of the work material and correspondingly varies the accuracy and consistency of the cut.

There is a need, therefore, for a portable laser processing system that is relatively lightweight and inexpensive to manufacture compared to previously known systems. Accordingly, it is an object of this invention to provide such a system.

Another object of this invention is to provide a laser processing system that is easy to use and maintain.

A further object of this invention is to provide a laser processing system capable of cutting intricate shapes in sheet material with reasonable speed, accuracy and consistency.

Additional objects and advantages of the invention will be set forth in the description that follows, and in part will be apparent from the description, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and obtained by means of the instrumentalities and combinations pointed out in the description and appended claims.

SUMMARY

To achieve the foregoing objects, and in accordance with the purposes of the invention as embodied and broadly described in this document, there is provided a laser processing system for cutting sheet work material. The laser processing system includes a laser generator for generating a laser beam for cutting the work material, a work surface for supporting the work material, a cutting head located above the work surface for

projecting the laser beam toward the work surface, a beam delivery system for coupling the laser beam to the cutting head and a drive system for moving the cutting head along a selected path over the work surface. The beam delivery system includes a flexible waveguide. A protective flexible sheath can be positioned over the waveguide. The protective flexible sheath can comprise a steel monocoil sheath. Alternatively or in addition, a flexible sleeve can be provided over the waveguide, the flexible sleeve having a conductive wire disposed therein for sensing a failure of the waiveguide and shutting the laser down in response to such a failure. The work surface can be covered at least in part by a heat-absorbing coating, which can comprise borosilicate. The laser processing system can be enclosed in a lightweight case, such as a case comprising molded plastic.

The system of the invention can be truly portable. It is small and light enough to be used on a desktop and can be moved from one location to another with ease. The system is easy to operate and maintain. It is rugged enough to be used in production applications where durability, repeatability, and stability are required for continued daily use. The system can cut and engrave work material with safety, speed and accuracy. Yet, it can be manufactured relatively inexpensively.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate the presently preferred embodiments and methods of the invention. Together with the general description given above and the detailed description of the preferred embodiments and methods given below, they serve to explain the principles of the invention.

FIG. 1 is a perspective view of one embodiment of a portable laser processing system according to the invention, showing the case open.

FIG. 2 is a perspective view of the laser processing system of FIG. 1 showing the case cut away to reveal components of the system.

FIG. 3 is a sectional side view of the system of FIGs. 1 and 2, taken through section line A—A.

FIG. 4 shows a perspective view of a presently preferred embodiment of the laser directing and focus assembly in accordance with the invention.

FIG. 4A shows another view of a portion of the laser directing and focus assembly of FIG. 4.

FIG. 5 shows a side view of one embodiment of the waveguide input assembly for

the system of FIG. 2.

FIG. 5A is an enlarged detail view of a portion of the assembly of FIG. 5.

FIG. 5B is an enlarged detail view of an alternative embodiment of a portion of the assembly of FIG. 5.

FIG. 5C shows an enlarged detail view of a section of the waveguide including a sleeve with embedded wires for sensing waiveguide failure and shutting the laser down.

FIG. 6 is a sectional side view of one embodiment of a laser cutting head according to the invention, taken through section line B—B, and including a sectional side view showing the vacuum system according to the invention.

FIG. 6A is a top plan view of the laser cutting head of FIG. 6.

FIG. 6B is a side view of the laser cutting head of FIG. 6.

FIG. 6C shows a perspective view of the laser cutting head of FIG. 6.

FIG. 7 is a sectional side view of an alternative embodiment of a laser cutting head according to the invention, taken through section line A, which embodiment includes two perpendicularly-oriented waveguides and a mirrored surface for directing the laser beam.

FIG. 7A is a top plan view of the laser cutting head of FIG. 7.

FIG. 7B is a side view of the laser cutting head of FIG. 7.

FIG. 7C is a front view of the laser cutting head of FIG. 7.

FIG. 7D is an enlarged detail view showing a configuration of the laser cutting head of FIG. 7 with end caps on the waveguides.

FIG. 7E is an enlarged detail view showing a configuration of the laser cutting head of FIG. 7 without end caps on the waveguides.

FIG. 8 is a sectional side view of another embodiment of a laser cutting head according to the invention, taken through section line A, which embodiment includes a tube jacket for directing the laser beam.

FIG. 8A is a top plan view of the laser cutting head of FIG. 8.

FIG. 8B is a side view of the laser cutting head of FIG. 8.

FIG. 8C is a front view of the laser cutting head of FIG. 8.

FIG. 9 is a sectional side view of still another embodiment of a laser cutting head according to the invention, taken through section line A.

FIG. 9A is a top plan view of the laser cutting head of FIG. 9.

FIG. 9B is a side view of the laser cutting head of FIG. 9.

FIG. 9C is a front view of the laser cutting head of FIG. 9.

FIG. 10 is a sectional side view of another embodiment of a laser cutting head according to the invention, taken through section line A, which embodiment includes a mirrored surface and a prism for directing the laser beam.

FIG. 10A is a top plan view of the laser cutting head of FIG. 10.

FIG. 10B is a side view of the laser cutting head of FIG. 10.

FIG. 10C is a front view of the laser cutting head of FIG. 10.

FIG. 11 is a sectional side view of still another embodiment of a laser cutting head according to the invention, taken through section line A.

FIG. 11A is a top plan view of the laser cutting head of FIG. 11.

FIG. 11B is a side view of the laser cutting head of FIG. 11.

FIG. 11C is a front view of the laser cutting head of FIG. 11.

FIG. 12 is a sectional side view of yet another embodiment of the laser cutting head according to the invention, taken through section line A, which embodiment includes a formed glass tube with a reflective coating for directing the laser beam.

FIG. 12A is a top plan view of the laser cutting head of FIG. 12.

FIG. 12B is a side view of the laser cutting head of FIG. 12.

FIG. 12C is a front view of the laser cutting head of FIG. 12.

FIG. 13 is a block diagram of the laser processing system according to the invention.

FIG. 14 shows a block diagram of the system control board according to the invention.

FIG. 15 shows a handheld computer display of a Main Frame screen for operating the system of the invention.

DESCRIPTION

Reference will now be made in detail to the presently preferred embodiments and methods of the invention as illustrated in the accompanying drawings, in which like reference characters designate like or corresponding parts throughout the drawings.

Overview

Referring to FIGs. 1-3, a laser processing system 10 according to the present invention includes a laser generator unit 11 for generating laser beam 20 and having an output optically coupled to a beam delivery system including a laser directing and focusing assembly 12 and an optical waveguide 13 optically coupled to a cutting head 18.

The laser directing and focusing assembly 12 is enclosed in a protective case (not shown) made of a suitable material for containing the laser beam 20, such as sheet steel or aluminum of a suitable thickness. Laser cooling fans 19 are provided to air cool the laser generator unit 11. A generally planar work surface 14 is provided for supporting a sheet of work material 16 to be cut by the laser processing system 10. The work surface 14 is perforated with holes 15 for providing a vacuum hold down of the work material. The vacuum for holding the work material to the work surface 14 is achieved with table fans 24, which also cool electronic circuitry of a control system 28 located beneath the work surface 14. The cutting head 18 is located above the work surface 14 and projects a laser beam 20 downwardly onto the top surface of the work material generally along a cutting axis 22, which is fixed relative to the cutting head 18 and which is oriented generally perpendicularly to the support surface 14 at its point of contact with the work material 16. The supporting system for the work material 16 and for the cutting head 18 is constructed and arranged so that the cutting head 18 and work material 16 are moveable relative to one another to allow the cutting axis 22 to be moved along an axis trace line having components in the two coordinate directions (X and Y) of the top surface of the work material 16. This relative motion is accomplished by an X-Y drive mechanism 26, which is described in more detail below. Attached to the cutting head 18 is a vacuum hose 30, which is in fluid communication with a vacuum assembly 32 for collecting and filtering fumes and particulates created by the laser vaporization of processed materials. A computer 27, such as a handheld computer, can be provided for cooperating with the control system 28 for controlling the laser processing system, as described below. Power supplies 25 are provided for powering the system 10. A lightweight case 29 encloses the system 10 and is provided with a hinged cover 31 for accessing the work surface 14.

Work Surface and Drive Mechanism

The work surface 14 includes an aluminum platen perforated with 1/16" diameter holes for the vacuum hold down of work materials. Preferably, the work surface is coated with a heat-absorbing material, such as borosilicate. This coating absorbs the heat generated by the laser at the focal point and also absorbs residual laser radiation, eliminating randomly scattered energy reflection. The absorption of heat and the elimination of reflectivity provides for greater safety and a significantly higher quality of cut on processed materials.

The X-Y drive mechanism 26 includes a carriage 21 to which the cutting head 18

is mounted and which holds the cutting head 18 above the work surface 14. The carriage 21 is movable relative to the work surface 14 and the work material 16 in a Y coordinate direction by sliding movement along the length of a Y bridge 45 extending in the Y coordinate direction and straddling the work surface 14. The Y bridge 45 is in turn movable in an X coordinate direction along the length of pair of X bridges 46 extending in the X coordinate direction at opposite sides of the work surface 14. The X-Y drive mechanism 26 achieves relative two-dimensional movement between the cutting head 18 and work material by controlling the positional relationship between the cutting head 18 and the work surface 14 with the work material being fixed to the work surface 14. In one advantageous embodiment shown in FIGs. 1-3, the X and Y drive 26 for producing relative motion between the carriage 21 and the work material in the Y coordinate direction includes a Y axis motor 70 and lead screw 72 and the X axis portion of the drive 26 comprises an X axis motor 74 and associated lead screw 76. When the motor 70 is operated, the lead screw 72 moves the carriage 21 in the Y coordinate direction, and when the motor 74 is operated, the lead screw 76 moves the carriage 21 in the X coordinate direction. The illustrated cutting axis 22 is fixed relative to the carriage 21, and therefore by combined operation of the motors 70 and 74, under control of the control system 28, the carriage 21 may be moved simultaneously in the X and Y coordinate directions to move the cutting axis 22 along a given axis trace line on the sheet material.

One suitable X-Y motion system includes a positioning slide system with lead screw and ball drive, such as model MS25L120 available from Thomson Industries, Inc. of Port Washington, New York. The system has a powered X and Y axis slide along with an idler slide on the Y axis. Another suitable X-Y motion system can include a linear motor slide system where the entire slide is the motor. The linear slide can allow for digital accuracy and speeds up to 160 inches per second. Still another suitable X-Y motion system is a belt-driven system such as plotter drives available from Graph-Tek of Ontario, Canada.

Laser and Beam Delivery System

Referring to FIGs. 2, 4, 4A, and 5, the output of laser generator 11 is optically coupled to the input of the laser directing and focusing assembly 12, the output of which is in turn coupled to the input of the waveguide 13. The directing and focusing assembly 12 includes a mirror 34 (not shown in FIG. 5) positioned for directing the laser beam 20 from the output of the laser generator 12 through a variable focus lens 36. The lens 36 is

a positive meniscus objective lens, which is positioned between the mirror 34 and the input of the waveguide 13 for focusing the laser beam 20 at the input of the waveguide 13. The focal distance from the variable focus lens 36 to the waveguide input can be varied using an adjustment screw 40 to provide an optimal focus of the laser beam at the waveguide input. The input end of the waveguide 13 is held in place by a collar 38, the position of which can be adjusted vertically by vertical adjustment screw 42 and horizontally by horizontal adjustment screw 44.

In one advantageous embodiment, the laser unit 11 is a 25-watt CO_2 laser, such as model 48-1 available from Synrad, Inc. of Mukilteo, Washington. The laser unit 11 is air cooled with two 3-inch fans 19 and can be laid on a side configuration. The waveguide 13 is a hollow optical waveguide. Such a waveguide eliminates the use of open air mirrors of previously known beam delivery systems. In a preferred embodiment, the waveguide 13 is a flexible silica tube coated internally with reflective silver or gold deposition. One such suitable waveguide is a hollow silica CO_2 waveguide having an inner diameter of 750 μm, which is commercially available from Polymicro Technologies of Phoenix, Arizona. As shown in FIGs. 5, 5A and 5B, at the waveguide input, the laser beam 20 is focused into the bore of the tube 50 and is transmitted internally through reflectivity. As shown in FIG. 5B, an optional pressed insert made of ceramic, quartz, steel or the like can be provided to helps protect the input end of the waveguide from damage by the laser beam 20. The beam 20 travels through air between reflections with minimal power loss. Since the beam travels through a set distance within the tube 50, the diameter of the beam and therefore the spot size at the input to the cutting head 18 remains constant, even during movement of the cutting head 18. This results in consistent accuracy, repeatability, and improved quality of the cut.

With this presently preferred embodiment, it has been determined that a beam diameter of 6mm at the focus lens 36 is desired for optimal focus into the waveguide 13 and transmission efficiency. To achieve this beam diameter, a beam expander (not shown) can be positioned between the mirror 34 and the focus lens 36. Alternatively, a series of beam folding mirrors (not shown) can be incorporated and positioned to achieve a beam length of approximately 45 inches to the focus lens 36 to allow the beam to spread to a diameter of about 6mm at the focus lens 36.

For safety, the waveguide 13 is enclosed in a flexible sheath 52, such as a steel monocoil sheath, that protects the waveguide 13 and acts as a barrier for containment of

the beam 20 in case of waveguide failure. As shown in FIG. 5C, for additional safety, the waveguide 13 optionally can be enclosed in a flexible sleeve 54 impregnated with micro-fine wires 56 that can act as a fuse in the laser power circuit. One material suitable for the flexible sleeve 54 is PTFE fluoropolymer resin, such as Teflon® fluoropolymer resin marketed by E.I. du Pont de Nemours and Company. In case of accidental breakage of the waveguide 13, the laser beam 20 will cut through the sleeve 54 and sever the wires 56, breaking the laser power circuit and resulting in the immediate shut down of the laser 11. Thus, this feature can serve as a redundant safety feature on the system.

The total containment of the laser beam within the protective sheath 52 eliminates the need for a metal enclosure around the entire laser system. Consequently, the case 29 can be fabricated from a lighter material, e.g., injection molded plastic such as that used to fabricate computer cases. This enables a dramatic decrease in the weight of the system 10 as compared to previously known systems. For example, in a preferred embodiment, the system 10 occupies a space approximately 26" L x 24" D x 6.5" H and weighs approximately 35 pounds, which enables quick relocation and transportation of the laser system for on site use. The case 29 can include a carrying handle, such as a retractable full-length carrying handle, for transporting the system 10, and and the machine may be set on its side for ease of transportation or storage.

Cutting Head

The output of the waveguide 13 is optically coupled to the cutting head 18 for directing and focusing the laser beam 20 toward the work surface 14. As shown in FIGs. 6 and 6A-6C, in one advantageous embodiment, the cutting axis 22 is perpendicular to the waveguide output axis 58 and the cutting head 18 redirects the laser beam 20 at angle that is perpendicular to the waveguide output axis 58. In this configuration, the cutting head 18 includes a generally cylindrical housing 60 that is rotatably held within a mount 61 that is attached to the carriage 21 and allows the housing 60 to swivel within the mount 61 about the cutting axis 22. The housing 60 has an externally threaded nipple 62 at its upper end for receiving the output end of the waveguide 13. A threaded collar 64 is rotatably attached to the protective sheath 52 near the output end of the waveguide 13 and can be screwed tight to tighten the waveguide 13 into position within the nipple 62. A mirror 64 positioned at the upper end of the housing 60, directs the beam 20 downwardly along the cutting axis 22. In the embodiment shown in FIG. 6, the mirror 64 is an off-axis parabolic mirror, which redirects and focuses the laser beam without lenses to give

the beam a power density at the top surface of the work material sufficient to cut the material as the cutting head 18 is moved along the line of the cut. At the lower end of the housing 60, an exhaust port 66 communicates with the vacuum hose 30. The vacuum hose 30 is in fluid communication with the vacuum assembly 32, which includes a vacuum fan 33 and also preferably includes replaceable filter material 36, such as an activated charcoal filter, for filtering the collected fumes and particulates.

Referring to FIGs. 7-12, other exemplary configurations of a cutting head are shown for directing and focusing the laser beam 20. As shown in FIG. 7, one alternative embodiment of the laser cutting head 18, includes two perpendicularly-oriented waveguides and a mirrored surface for directing the laser beam 20 downward. At the lower end of the housing 60 is a lens assembly that includes a threaded shrowd that holds two lenses (a culmination lens and a positive meniscus objective lens) to focus the laser beam to the work surface. This shrowd provides further protection from the laser beam and also provides a vacuum chamber to eliminate fumes at the lasing point via an exhaust port 66 like that previously discussed. Alternative, the shrowd can be in the form of cone-shaped lens holder (not shown) attached to the lower end of the housing 60 and having an air intake hole in the wall of the cone below the lenses for creating an internal vortex of pressurized air to keep contaminants off the lens. This vortex is achieved according to the Bernoulli principal by positioning the end of the vacuum hose 32 near the lower opening of the cone-shaped holder air below the lenses and drawing air by the lower opening of the cone, thereby creating a region of high pressure near the lens to keep the lens free of contaminants generated by the laser cutting process. As shown in FIGs. 7D and 7E, respectively, the waveguides can be provided with or without end caps.

FIG. 8 depicts another embodiment of the laser cutting head 18, which includes a curved tube jacket that encloses and bends a waveguide within the housing 60 for directing the laser beam.

FIG. 9 illustrates a cutting head 18 that utilizes a mirrored surface and a lense assembly to direct the laser beam.

FIG. 10 shows a cutting head that includes a mirrored surface and a prism for directing the laser beam.

FIG. 11 depicts cutting head having an in-line waveguide direct configuration to the focusing lenses.

FIG. 12 illustrates a laser cutting head 18 that includes a formed glass tube with a

reflective coating on an internal bore for directing the laser beam.

Control System

FIGs. 13 and 14 show block diagrams of the control system 28 for controlling the operation of the laser processing system 10. As shown in FIGs. 13 and 14, the control system includes an on-board processor 100, a laser beam control and generation interface 102, an X-Y motor motion control system 104, a universal AC power supply system and control interface 106, a lid motor interface and control (not shown), an interface 110 to a computer device utilizing any one of a number of communication protocols, fan and vacuum control interfaces 112 and system monitor and status interfaces 114, 116, 118.

In a presently preferred embodiment, the on-board processor 100 is implemented using an H8S/2144A micro controller or H8S/2148 micro controller with an internal 32-bit architecture available from Hitachi, Ltd. The micro controller 100 accesses internal memory as well as external memory located on the control board 28.

Information needed for the lase cutting process is downloaded from an external computer 27, such as a personal computer operating with the Windows operating system, via the computer interface 110. After this information is downloaded to the control system 28, it is stored in the local memory and can be used to drive the laser system 10.

In the presently preferred embodiment, the laser 11 is a self-contained unit requiring external stimulus for standby and lase operation. Control such as turning the laser on/off, laser beam power (intensity) settings, standby, and feedback from the laser are provided via a digital interface between the micro controller 100 and the laser 11. A pulse width modulated (PWM) output from the micro controller 100 is used to provide a PWM command to drive the laser beam power. The PWM command input frequency can vary up to 20 KHz. Changing the clock duty cycle to the laser 11 can vary the laser power from standby to full power lase operation. Reducing the modulated clock duty cycle will reduce the laser beam power and conversely increasing it will increase its power. The micro controller 100 can provide complete control over these parameters and thereby can provide smooth control of the laser beam.

The X-Y motor motion control system 104 is used to control the stepper motors 70, 74 that move the carriage 21 and the cutting head 18 across the cutting surface to lase the desired image onto the work material 16. The micro controller 100 interfaces to motor control and interface circuits that drive these stepper motors 70, 74. The X-Y motor control interface utilizes a second micro controller to micro step the motors 70, 74

for smooth operation and to minimize the reverse current effects caused by the inductance of the motors. Information required for the movement and exact location of the cutting head 18 is provided through the software at the control panel. The control panel processor interprets the data to be lased onto the work material and sends commands to the X-Y motion controller. The X-Y motion controller provides phase information to the motors slowing or speeding the X or Y movement across the work material.

The laser beam control and generation interface 102 includes I/O ports for the monitor and control of the laser 11. These interfaces are coupled to the micro controller for processing. In one advantageous embodiment, outputs are provided for laser fault shutdown due to over temperature or over/under voltage or when a fault occurs, remote interlock, temperature at 54 degrees C, remote keyswitch, remote lase LED output, and remote ready LED.

Board level status is provided directly from the micro controller 100 and displayed on an eight segment display 120. Numeric codes defined in the system software can provide the user with instant feedback of system status. In cases where field interface to the laser unit 11 is required, a serial port with a programmer interface 116 is available to upload new firmware or troubleshoot system problems.

In one embodiment, the power system 106 for the laser processing system utilizes a universal AC front end interface to provide 380 volts DC from 120 to 240 volts AC, 50/60 cycle. The DC voltage sources needed for the system +5, +12, and +30 volts DC are generated from the 380 volts DC by the respective supply. Two switches (not shown) are provided for switching the system on and off. A main AC switch acts to switch the main power to the unit. A standby switch, provides the ability to turn off only the outputs of the low voltage supplies thus maintaining the high voltage energy for quick restoration of power and minimize the stress on the AC power mains.

The control system also can control a motor (not shown) to lift and close the lid covering the laser cutting surface and allowing access to the media area. A suitably located switch (not shown) can sense whether the lid is open or closed and provide a sensing signal to the micro controller, and the micro controller can send a control signal to a lid motor to open or close the lid.

The micro controller 100 also communicates with the several fan and vacuum control interfaces 112 to independently optimize control over the laser cooling fans 19, the table fans 24 and the vacuum fan 33.

The micro controller 100 interfaces to an external computer that supplies the coded information needed for driving the laser 11 and X-Y motion system 26. The high level processing of the information is performed in this computer prior to download to the laser system micro controller 100. In one presently preferred embodiment, the laser system of the invention can be controlled by a handheld computer control device 27, such as a Pocket PC or other WinCE or Embedded WinNT based device.

The system shown in FIGs. 13 and 14 depicts a specific handheld computer, but it will be understood that the system may operate with various handheld computers readily available on the market. The handheld computer 27, operating in cooperation with the software described below, can download raster and vector drawings and images from a host computer and can therefore make the laser system completely self-contained. The handheld computer and software control the laser 11 and also provides for drawing manipulation and editing. In the preferred embodiment, a drawing grid with all necessary drawing functions is included in the software to design and output entire drawings on the handheld computer 27. Bitmap images may also be downloaded to the handheld computer for editing and processing for laser engraving. Also in a presently preferred embodiment, the system can use pull down menus for sophisticated control and also can enable the sensing of material thickness on the work surface with an infrared LCD and automatic power, speed and pulse settings for the machine. The various control settings may be fine tuned for any desired configuration and cutting effect.

The handheld computer 27 can include an infrared port 122 allowing for a wireless link to a host computer to transfer CAD data to the control system 28. This data may be downloaded to the laser system 10 by infrared transfer via the infrared interface 122 from the handheld computer 27. In addition, CAD data can be transferred to the control system 28 using a compact flash memory 124. Other interface media can include, parallel, wireless and Ethernet for LAN connection or modem for connection with the Internet.

Software Specifications

Software for the system includes controller board software, a graphic user interface and software for the handheld computer 27, and software for communication with the control board 28. Each of these will now be described.

Control Board Software

The control board software performs all the tasks related to the laser plotter hardware. The controller board software includes the following functional modules: communication with handheld computer via serial port; processing of the job data; control of the X -Y motion system; laser beam modulation; fan control; temperature control; and support for the auxiliary communication ports (RS232, parallel). The software programs to operate the Hitachi micro controller described herein have been developed in C language using a Hitachi's C compiler and linker. It will be understood to those of skill in the art, however, that other suitable micro controllers are available and that other suitable software programs could be developed to perform the described functions.

The protocol for communication with the handheld computer is described below. The handheld computer 27 acts as the communication master while the controller board 28 acts as the slave. The RS232 port 110 utilizes channel 1 of the Serial Communication Interface (SCI) of the H8S/2148 micro controller. The program initializes the SCI upon start and then all communication is driven by interrupts. The program utilizes all four types of the SCI:

- Received-data-full interrupt is used for capturing data received from the handheld computer 27 and can activate the data transfer controller (DTC) for a fast transfer to the RAM.
- Receive Error interrupt handles error condition during receiving data process.
- Transmit-data-empty interrupt processes Tx frame data from RAM and can activate the DTC.
- Transmit-end Interrupt can be used to inform the processor that the data has been transferred and a new communication cycle can start.

The laser plotter settings for the cutting job and CAD data are stored in the onboard RAM to be processed during plotting. The job settings and data are transferred to the controller board 28 using commands 10 and 12 respectively (see Command Table below).

The X-Y motion system stepper motors 70, 74 are controlled via the 8 bit parallel I/O port. The position settings and travel information are included in the CAD data.

The laser beam strength is controlled via an 8-bit PWM. The modulation settings are controlled by values also included in the CAD data.

Control for the laser cooling fans 19, the table fans 24 and the vacuum fan 33 is provided by the micro controller 100 using one of its parallel ports.

A temperature sensor 126 placed on the laser body, is connected to an onboard analog-to-digital converter (A/D). The micro controller 100 reads this temperature and controls the temperature by controlling the laser cooling fans 19.

The auxiliary serial or parallel communication port 116 allows for another means of the connection from the host computer to the handheld computer 27. The parallel data is converted to a serial form and fed to the handheld computer's serial port.

Pocket PC Graphic User Interface (GUI) and Software

In one embodiment, the Pocket PC GUI is developed in Visual C++ employing the Microsoft Foundation Class library (MFC). Microsoft embedded Visual Tools for Pocket PC was used for the development tools.

After the program start and initialization a Main Frame screen 130 is displayed on the computer display as shown in FIG. 15. The components of the Main Frame screen 130 include a window with an outline of the work area 132, a toolbar (not shown) and a menu bar 136. The work area window 132 displays two rulers 134, an outline of the work surface (17" x 11") and a reference mark for a home position. After the data is loaded, the outline to be cut is displayed. The toolbar includes a New button for opening a new job, getting job information and settings, an Open button for opening an existing job and loading data from memory, a Save button for saving the current information and data, a Run button for starting and stopping the cutting process, a Zoom In button for enlarging the object shown on the screen, a Zoom Out button for reducing the object shown on the screen, a Settings button and a Help button.

The menu bar 136 includes the following items with explanation in brackets:

- Job
  - New (open new job, get job information and settings)
  - Open (open existing job and load data from memory)
  - Save (save the current information and data)
  - Save As (save the current information under new name)
  - Import (import .BMP or .DXF file)
  - ——————
  - Job Settings (display job information and settings)
  - Move Outline (move the cut outline/ reference point)
  - ——————

- Run (start/stop cutting process)

o Edit
- Undo (undo last change)
- Cut (cut selected object)
- Copy (copy selected object to clipboard)
- Paste (paste from clipboard)
- Delete (delete selected object)

- Select All (select all objects)
- Select Object (select one object)
- Select Group (select group of objects)

- Draw Line (draw Straight, Freeform or Scribble cutting line on the work area)
- Draw Rectangle (draw Rectangle object cutting line on the...)
- Draw Ellipse (draw Elliptic object cutting line on the...)

- View
- Zoom In (Enlarge the object on screen, apply scrollbars)
- Zoom Out (Reduce the object...)
- Full Screen (Set screen to normal view)

- Grid (Switch the grid On/Off, select Grid granularity)
- Rulers (Switch rulers On/Off, select units)

- Format
- Line Settings (set thickness and color of the selected line)
- Grid Settings (in inches)
- Raster Settings (in inches)

o Tools
- About Laser (display information about program)

- Diagnostics (Start self-diagnostic script)
- Test Plot (cut a test pattern)
- Home Position (bring head to the home position)

A Job Settings dialog is displayed in response to the following menu selections: Job -> Job Settings. The Job Settings dialog contains all of the information related to the current project:

- name of the source (DXF or BMP) file – usually the job is named after this file
- mode of operation (vector or raster)
- number of objects per sheet of material
- coordinates of the reference point
- material type
- material thickness
- motor steps / raster

Apart from the Graphical User Interface functions, the software running on the handheld computer 27 performs several other important functions, including:

- Interface to a host computer
- Conversion of downloaded CAD data in such way that the controller board can drive the X-Y motion mechanism and modulate the laser beam
- Storage of the converted data and the project settings
- Display the outline or bitmap on the work area
- Support of the vector or raster operational modes.
- Simple editing functions with or without direct output to the controller.

Software for Communication to the Control Board

The communication to the control board 28 is provided via a serial port (RS232) This software module performs low level hardware functions for communications between the GUI and the controller board and also was developed in C++ language, using Microsoft embedded Visual Tools for Pocket PC.

In the presently preferred embodiment, the interface to the control system 28 is based on a serial communication via an RS232 port. This allows for detaching the handheld PC from the laser bed and operating it from a short distance. It will be understood, however, that other types of connections, such as a wireless connection could also be used for communication between the computer and the control board 28.

In a presently preferred embodiment, communication between the handheld 27 computer and the control system 28 is implemented using an RS232 asynchronous channel. The channel is set to 115.2kBps, 8 bit, No Parity and 1 Stop bit. The handheld computer is the communication master, responsible for maintaining the communication running all the time. Every command request (CmdType=0) must be acknowledged by a response. If the results are available immediately the controller responds with command completed (CmdType = 9). If the response is not available immediately then controller responds with a "poll" ('OK' or 'CMD_ERR' in the data field, CmdType=1), and send results with (Cmd_Type = 8, CMD_COMPLETED). This assures that the command was understood. The handheld computer will repeat the last command upon a receipt of the CMD_ERR response. If the next response is again the CMD_ERR an error is called out and laser operation is interrupted.

During an idle time, a regular polling takes place as an assurance of a reliable connection, in this situation the handheld computer sends command 00 – Poll Request . If the communication channel gets interrupted, the controller will stop the cutting process until the communication has successfully resumed.

The communication is byte oriented, with all the data passed in a form of frame. The communication frame has the following format:

Communication Frame Format

Flag	Dest. Addr.	Sourc Addr.	Length	CmdType	Cmd	Data	LRC	Flag
1 Byte	1 Byte	1 Byte	1 Word	1 Byte	1 Byte	(Length-4) * Byte	1 Byte	1 Byte
0x7e .	Note 1)	Note 1)	No. of Data Bytes	See Par. 0	See Par. 0	See Par. 0 .	LRC is calculated over the header and data	0x7e

Note that addresses are allocated as follows:

- 00 – 7F Controller Boards
- 80 – FE PC
- FF Broadcast (as destination).

CmdType Field

Bit	Meaning

7	0 – command (response expected) 1 – alarm (no response expected)
6	N/A
5	N/A
4	N/A
3	1 – command completed, no further data
2	1 – status request (in the middle of lengthy activity)
1	0 – initialize command 1 – stop action and report status
0	0 – command request 1 – command response

Examples:

- 00 command request (Pkt/PC, Master)
- 01 command request acknowledgement (poll) – OK, FRM_ERR or CMD_ERR, when command still in progress(Controller)
- 02 command stop (Pkt/PC, Master)
- 03 response to command stop usually with a result string, (Controller)
- 04 status request (Pkt/PC, Master)
- 05 response to status request (usually with a status string) , (Controller)
- 08 command completed, after a lengthy process(Controller)
- 09 command request acknowledgement (poll) – OK Completed, FRM_ERR or CMD_ERR, when command completed (Controller)

Cmd Table

Cmd	[Hex]	Command	Additional Response – command completed (separate frame from the acknowledge frame).
0		**System Commands Group**	
0	0	Poll Request	N/A
0	1	Identify	Returns system info.
0	2	Self test	Returns results
0	F	Soft Reset	Reset Completed.
1		**Configuration Group**	
1	0	Load Configuration String. Note1.0	N/A
1	1	Return Configuration String	Returns Config. String. Note1.0
1	2	Set Power Level Byte. Note 1.2	N/A
1	3	Set Speed Level Byte	N/A
1	4	Set Plot Resolution Byte (motor steps / raster step [1 – 255]).	N/A
1	5	Set Dots/Raster Step [1 – min. res.]	N/A
2		**Head Movement & Plotting Group**	

2	0	Move head to the Home Position	Cmd Completed.
2	1	Move Head to delta Position. 2.1	Cmd Completed
2	4	Plot Straight Line. Note 2.4	Cmd Completed
2	5	Plot Curved Line. Note 2.5	Cmd Completed
2	6	Plot Monochrome Bitmap Line – CW direction. Note 2.6	Cmd Completed
2	7	Plot Monochrome Bitmap Line – CCW direction. Note 2.6	Cmd Completed
2	8	Plot 256 level of Gray Bitmap Line – CW direction. Note 2.8	Cmd Completed
2	9	Plot 256 level of Gray Bitmap Line – CCW direction. Note 2.8	Cmd Completed
2	A	Plot Polyline. Note 2.A	Cmd Completed

Notes:

1.0 Configuration String:

- Head Travel Speed (Byte)
- Adjusted Home position from point 0,0 - X, Y (Both long values)
- Current Plot Power Level (Byte) - 0 – 200 (0.5% steps)
- Current Plot Speed level (Byte)
- Current Plot Resolution Motor Steps/raster step(Byte)
- Current Dots/Raster Step (Byte)

1.2 Set Power Level Byte:

- one Byte: - 0 – 200 (0.5% steps)

2.1 Move Head to delta position:

- delta X (long)
- delta Y (long)

2.2 Switch Laser On/Off:

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Step Y2	Step Y2	Step X2	Step X2	Step Y1	Step Y1	Step X1	Step X1

Binary values are coded as follows:

- 00 = no step
- 01 = +step
- 10 = -step
- 11 = undefined

2.6 Plot Monochrome Bitmap Line:

Sequence of Bitmap Bytes, each bit in the Byte represents Power On when 1 or Power Off when 0 respectively. Bits are organized from left to right direction, the bit 7 is on the left.

2.8 Plot 256 level of gray Bitmap line:

Sequence of Bytes, each representing one dot – ff = black (Laser on full power), 0 = white (Laser Idling). The ordinary color bitmap has 3 bytes per dot. The 256 level of gray must be converted by the Pkt/PC.

2.A Plot Polyline:

Sequence of long integers X,Y pairs.

CONCLUSION

From the foregoing, it can be seen that the portable laser processing system of the present invention provides numerous advantages. Such a system can be truly portable. It is small and light enough to be used on a desktop and can be moved from one location to another with ease. The system is easy to operate and maintain. It is rugged enough to be used in production applications where durability, repeatability, and stability are required for continued daily use. The system can cut and engrave work material with safety, speed and accuracy. Yet, the system can be manufactured relatively inexpensively.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details, representative devices, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

WHAT IS CLAIMED IS:

1. A laser processing system for cutting work material, the system comprising:

   a laser generator for generating a laser beam for cutting the work material;

   a work surface for supporting the work material;

   a cutting head located above the work surface for projecting the laser beam toward the work surface;

   a drive system for moving the cutting head along a selected path over the work surface; and

   a beam delivery system for coupling the laser beam to the cutting head, the beam delivery system including a waveguide.

2. The laser processing system according to Claim 1 wherein the beam delivery system further comprises a protective flexible sheath over the waveguide.
3. The laser processing system according to Claim 2 wherein the protective flexible sheath comprises a steel monocoil sheath.
4. The laser processing system according to Claim 1 wherein the beam delivery system further comprises a flexible sleeve over the waveguide, the flexible sleeve having a conductive wire disposed therein.
5. The laser processing system according to Claim 1 wherein the work surface is covered at least in part with a heat-absorbing coating.
6. The laser processing system according to Claim 5 wherein the heat-absorbing coating comprises borosilicate.
7. The laser processing system according to Claim 1 wherein system is enclosed in a lightweight case.
8. The laser processing system according to Claim 7 wherein the lightweight case comprises molded plastic.
9. The laser processing system according to Claim 1 further comprising an evacuation system for removing and filtering contaminated air near the work surface.
10. The laser processing system according to claim 1 wherein the evacuation system comprises an activated charcoal filter system.

11. The laser processing system according to claim 1 wherein the evacuation system comprises a high pressure side to keep the reflecting lens in the beam delivery system clean from fumes generated from the cutting process.

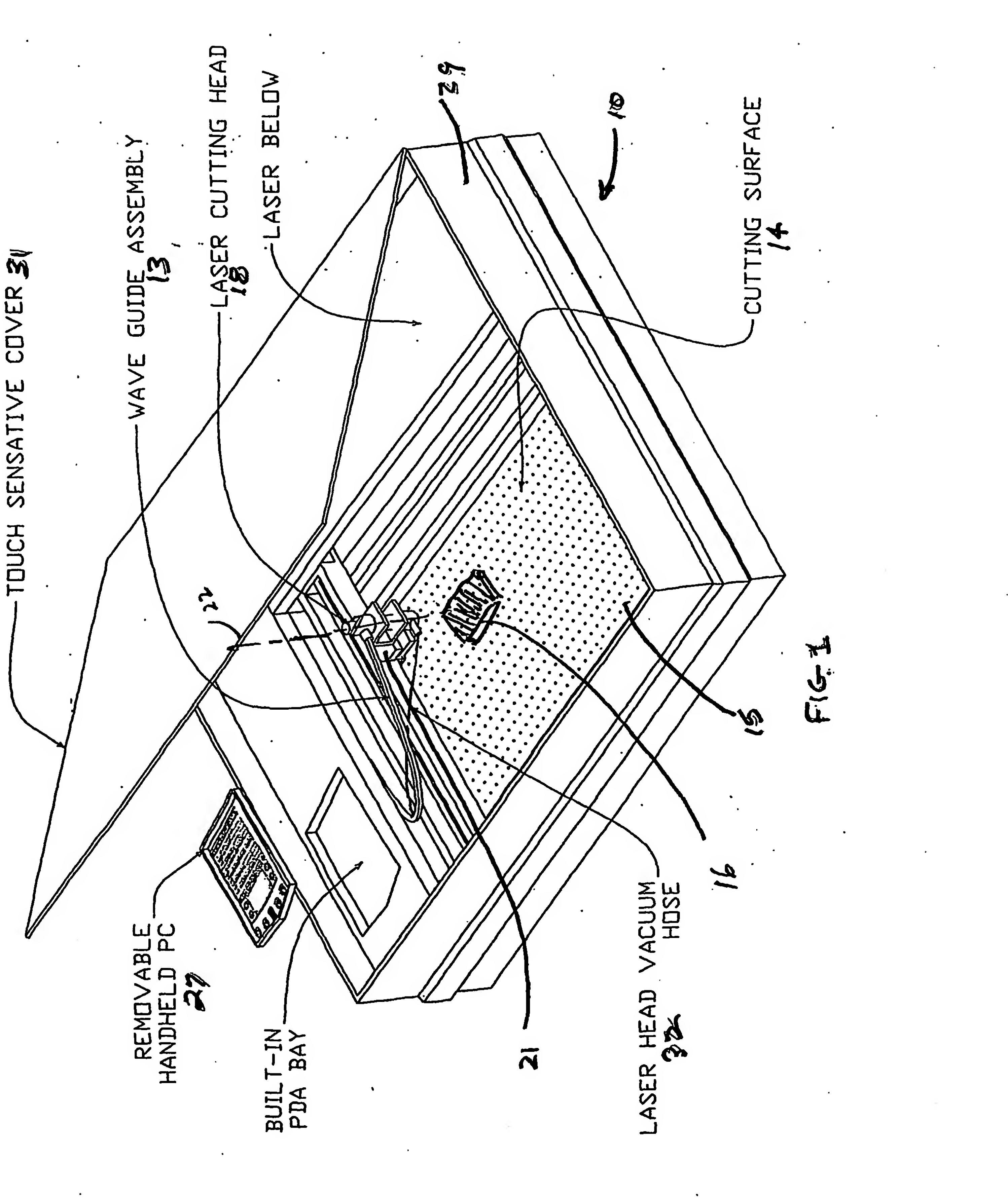

TOUCH SENSATIVE COVER 31
WAVE GUIDE ASSEMBLY 13
LASER CUTTING HEAD 18
LASER BELOW
29
10
CUTTING SURFACE 14
22
15
16
REMOVABLE HANDHELD PC 27
BUILT-IN PDA BAY
21
LASER HEAD VACUUM HOSE 32

FIG. 1

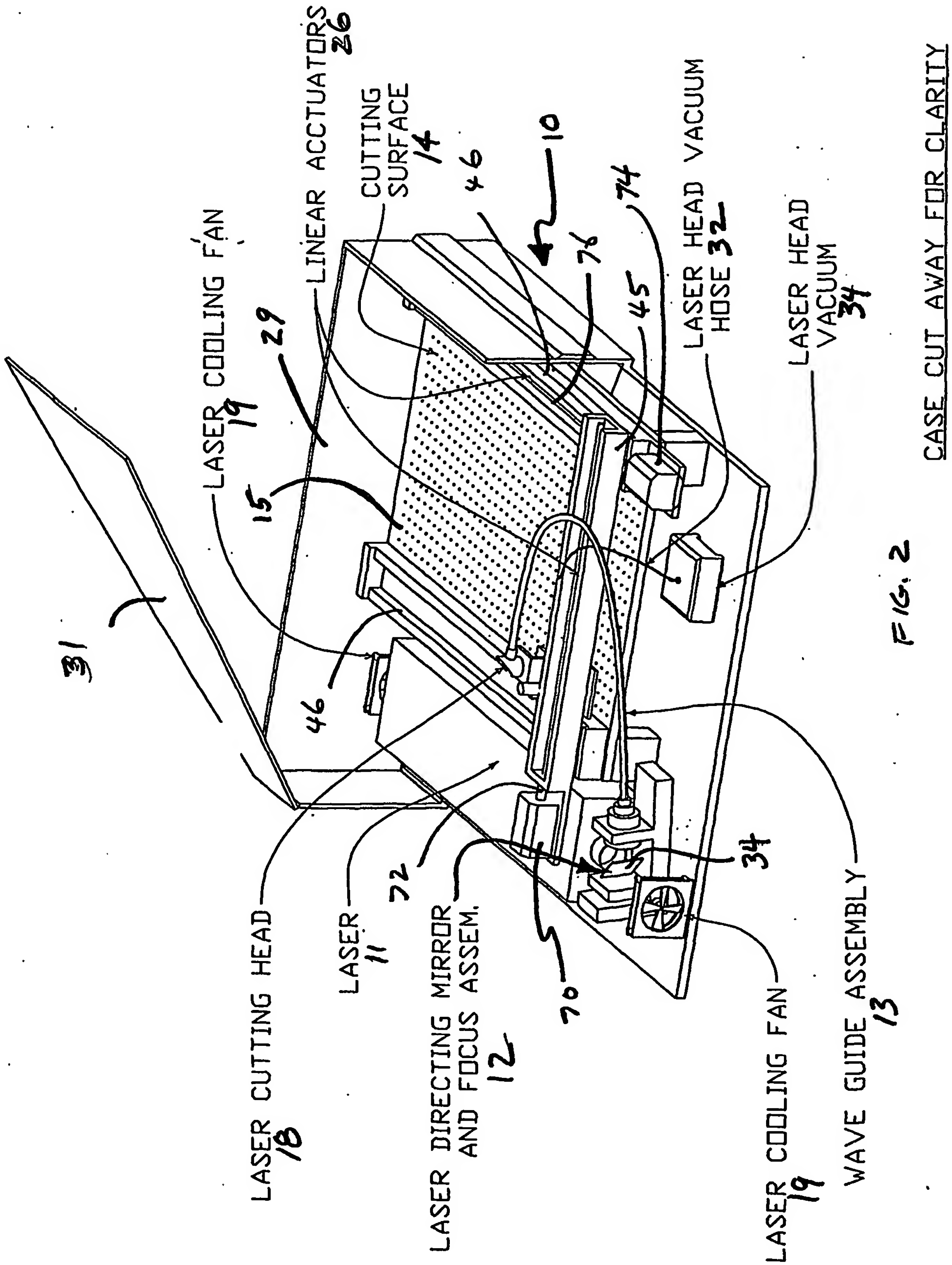

LINEAR ACCTUATORS 26
CUTTING SURFACE 14
LASER COOLING FAN 19
LASER HEAD VACUUM HOSE 32
LASER HEAD VACUUM 34
10
46
76
74
45
29
15
31
46
LASER CUTTING HEAD 18
LASER 11
LASER DIRECTING MIRROR AND FOCUS ASSEM. 12
72
70
34
LASER COOLING FAN 19
WAVE GUIDE ASSEMBLY 13
CASE CUT AWAY FOR CLARITY

FIG. 2

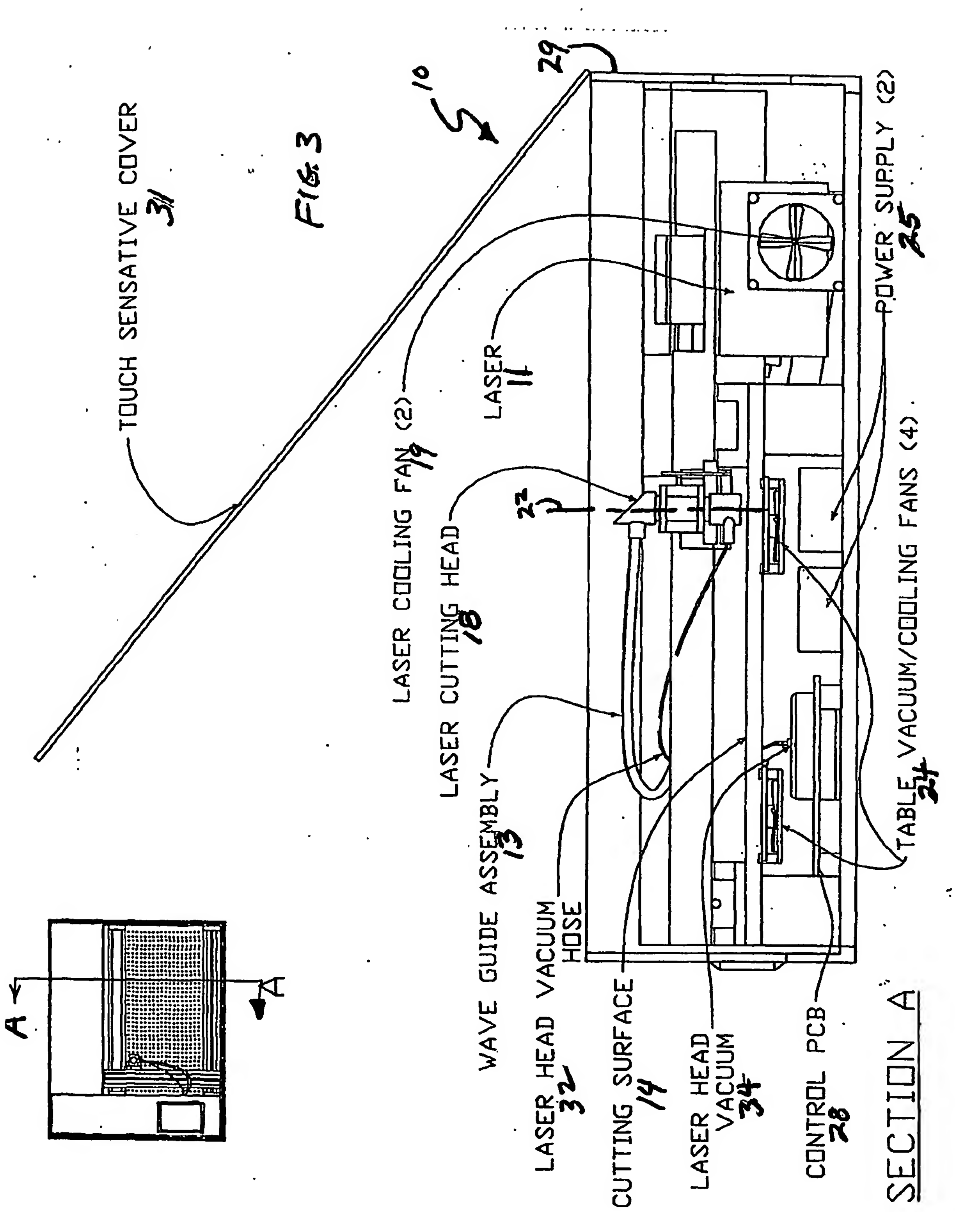


FIG. 3
10
29
TOUCH SENSATIVE COVER 31
LASER COOLING FAN (2) 19
LASER 11
POWER SUPPLY (2) 25
LASER CUTTING HEAD 18
22
TABLE VACUUM/COOLING FANS (4) 24
WAVE GUIDE ASSEMBLY 13
LASER HEAD VACUUM HOSE
LASER HEAD 32
CUTTING SURFACE 14
LASER HEAD VACUUM 34
CONTROL PCB 28
SECTION A
A
A

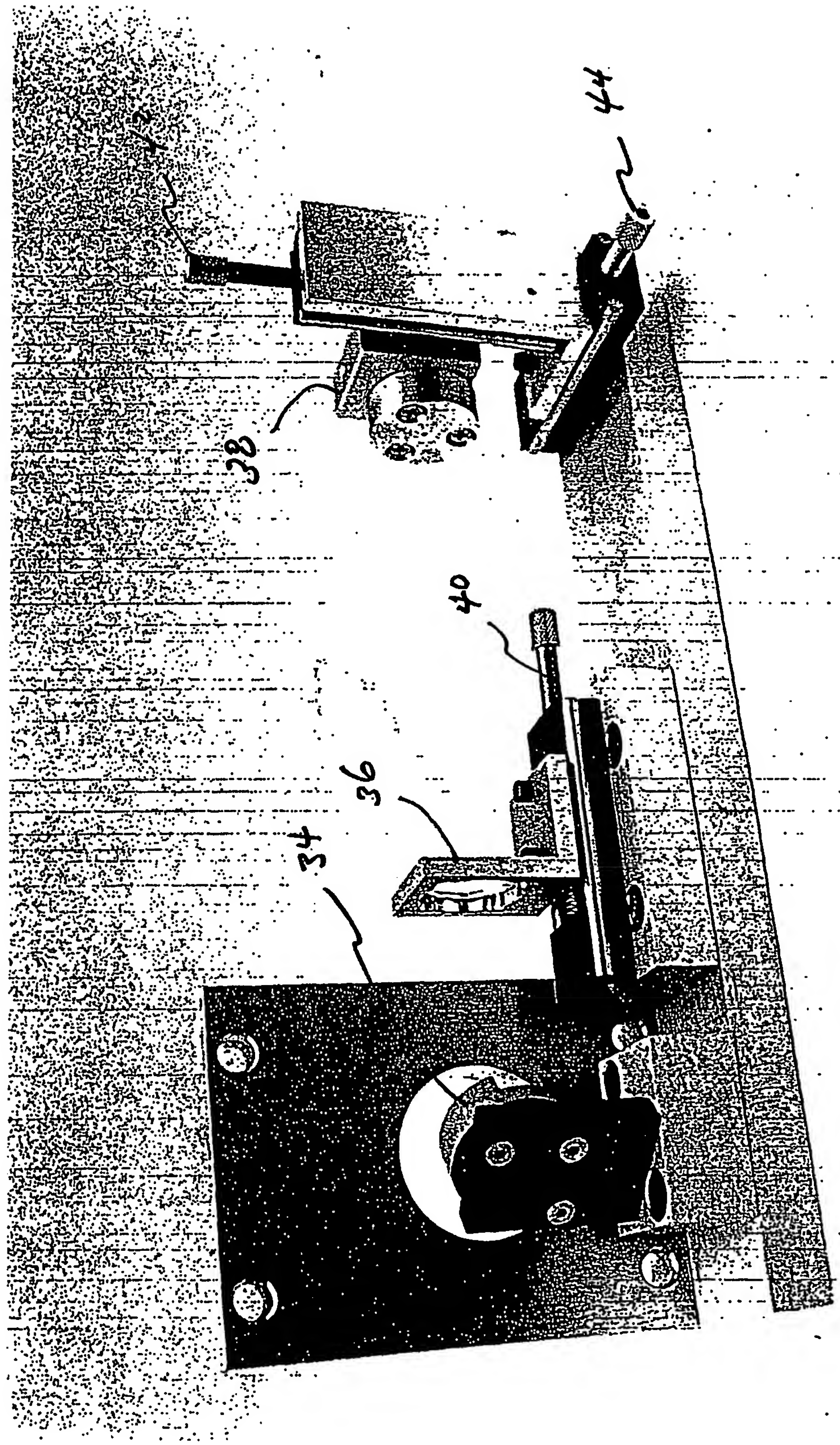


FIG. 4

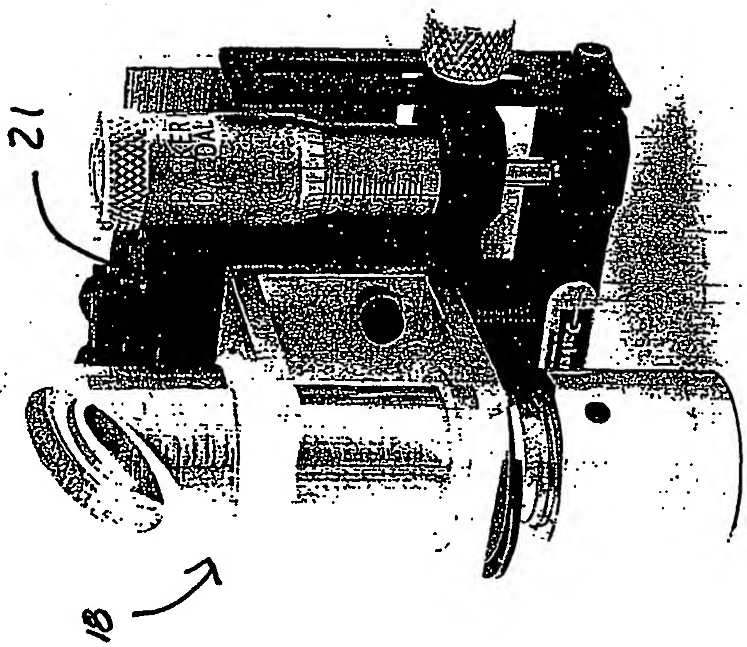


FIG. 6C

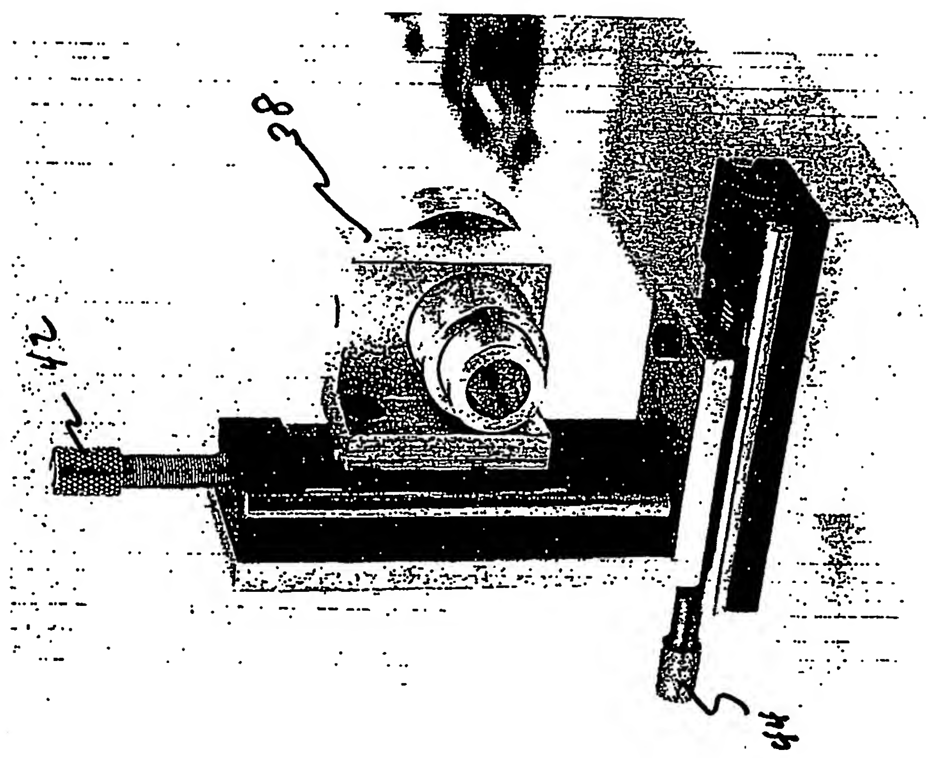


FIG. 4A

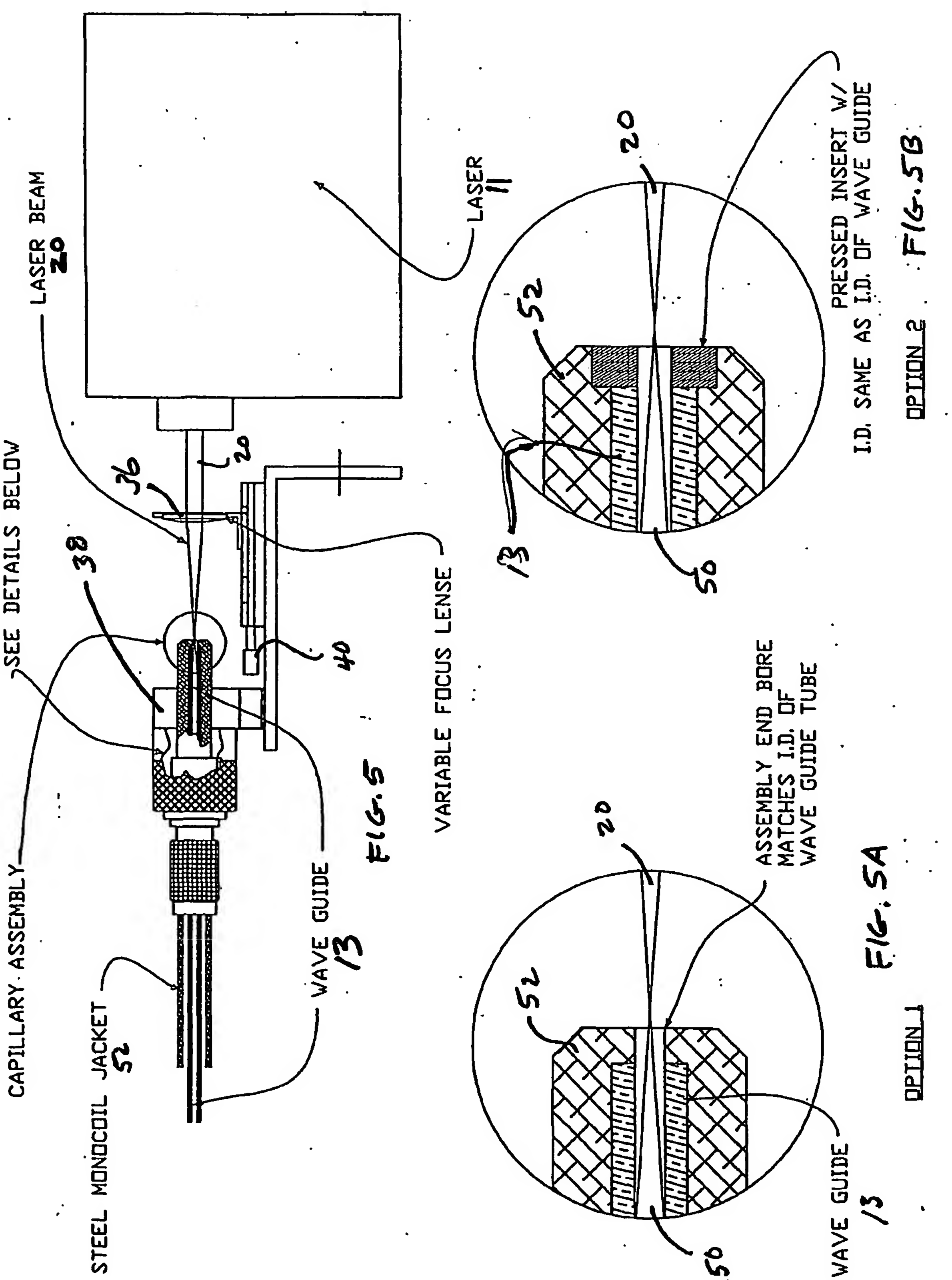


FIG. 5

FIG. 5B

FIG. 5A

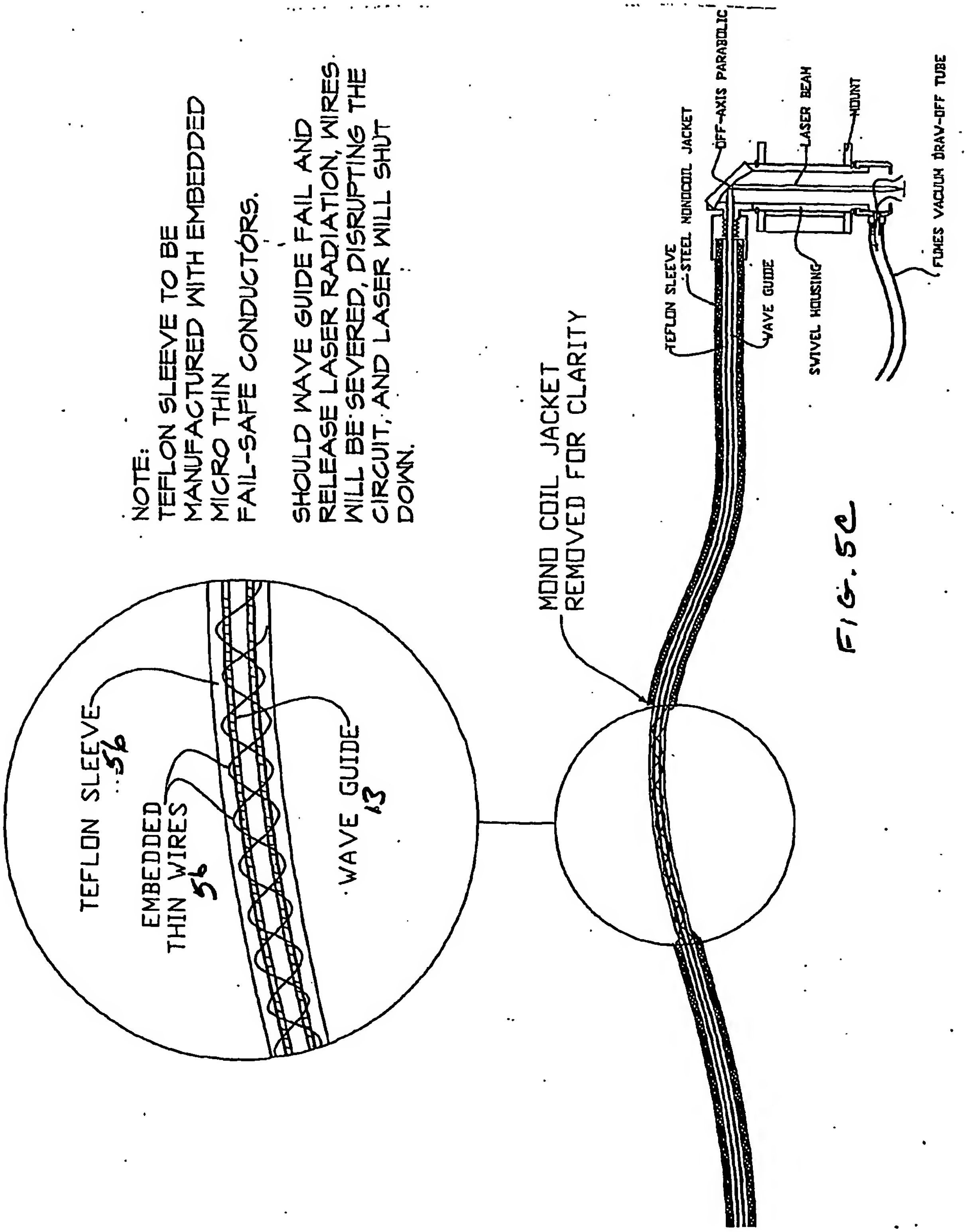

NOTE:
TEFLON SLEEVE TO BE MANUFACTURED WITH EMBEDDED MICRO THIN FAIL-SAFE CONDUCTORS.
SHOULD WAVE GUIDE FAIL AND RELEASE LASER RADIATION, WIRES WILL BE SEVERED, DISRUPTING THE CIRCUIT, AND LASER WILL SHUT DOWN.
MONO COIL JACKET REMOVED FOR CLARITY
TEFLON SLEEVE 56
EMBEDDED THIN WIRES 56
WAVE GUIDE 13
TEFLON SLEEVE
STEEL MONOCOIL JACKET
OFF-AXIS PARABOLIC
LASER BEAM
MOUNT
FUMES VACUUM DRAW-OFF TUBE
SWIVEL HOUSING
WAVE GUIDE

FIG. 5e

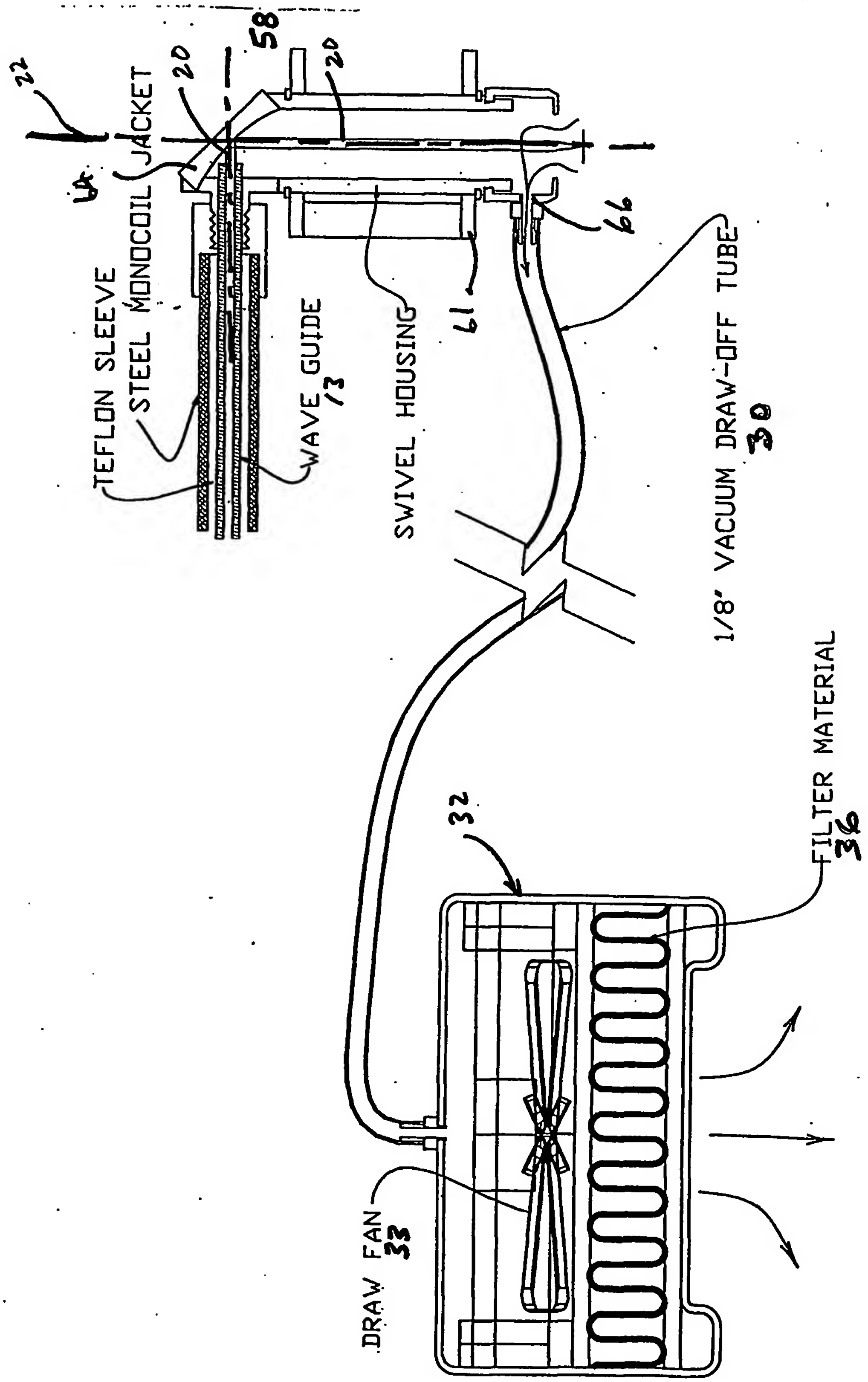
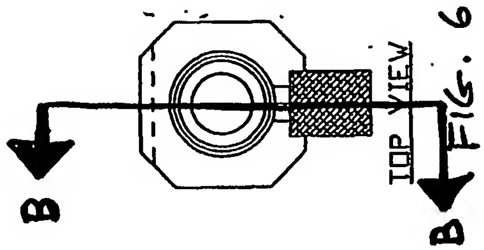
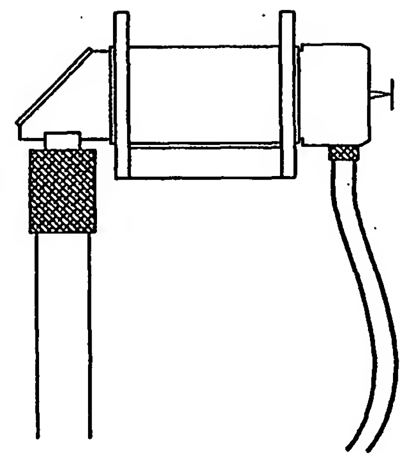

22
64
TEFLON SLEEVE
STEEL MONOCOIL
JACKET
20
58
20
WAVE GUIDE
13
SWIVEL HOUSING
61
66
1/8' VACUUM DRAW-OFF TUBE
30
FILTER MATERIAL
36
32
DRAW FAN
33

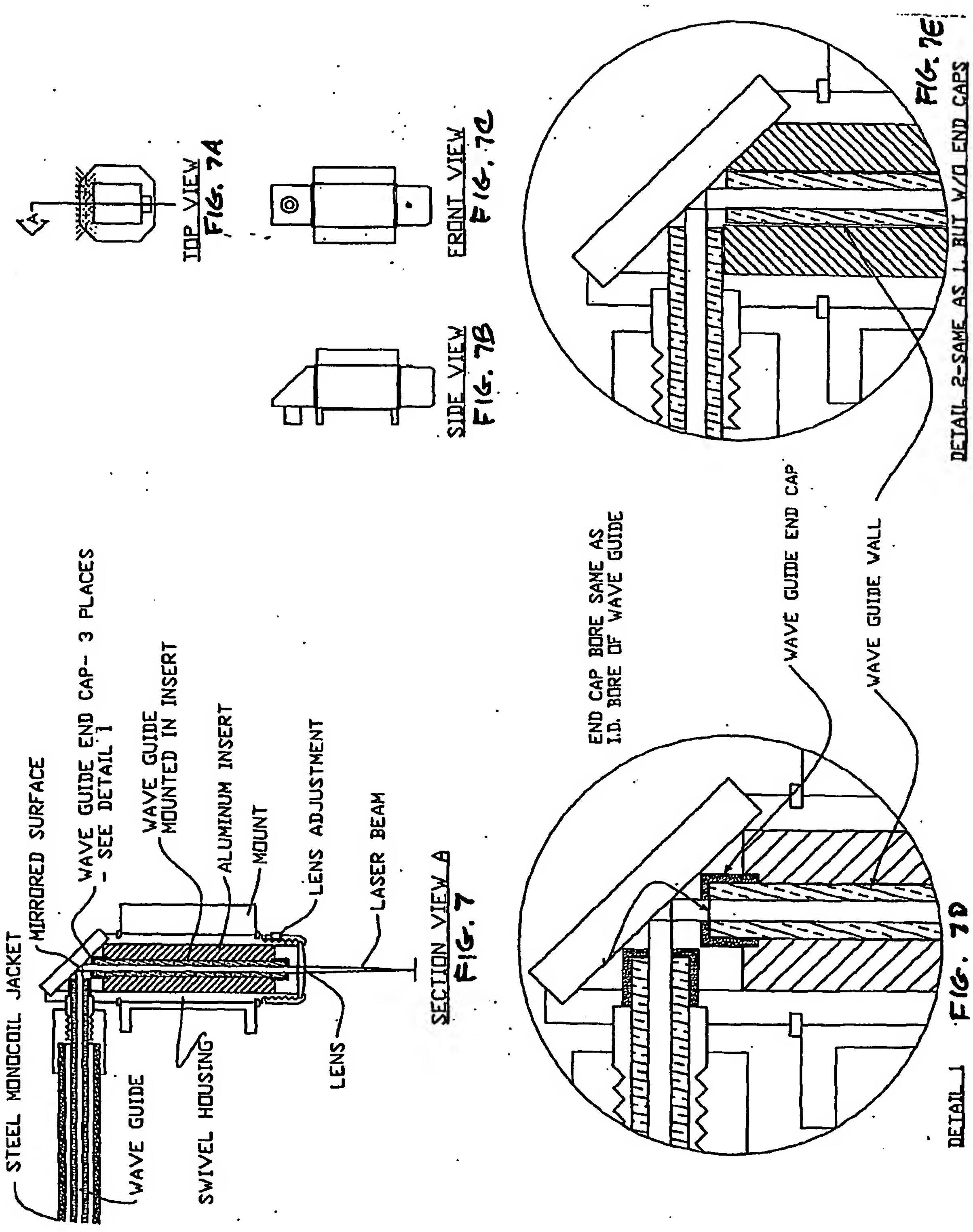
FIG. 6

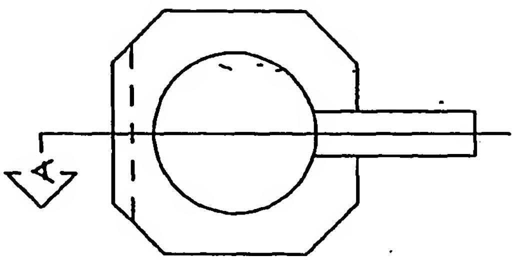


TOP VIEW
FIG. 6A

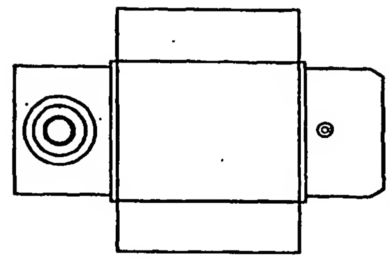


SIDE VIEW
FIG. 6B

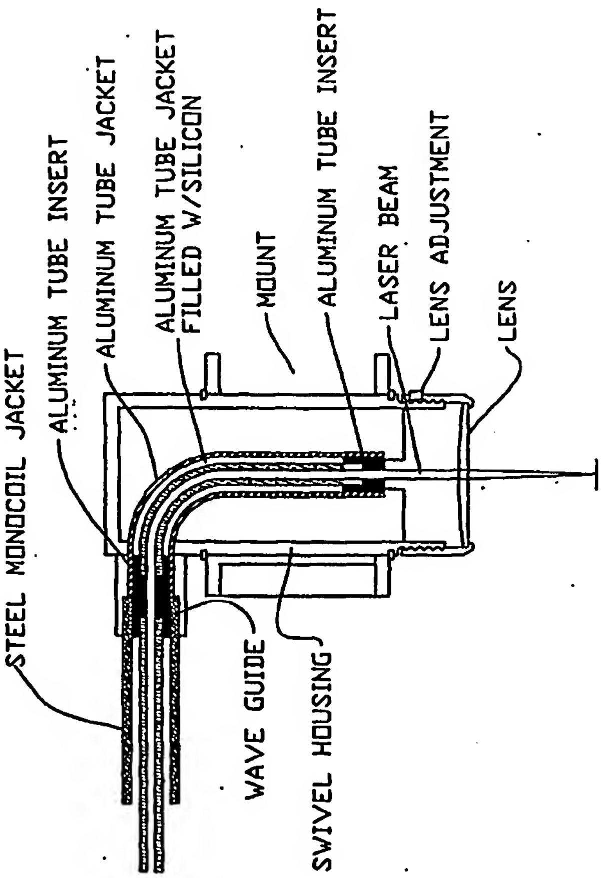

STEEL MONOCOIL JACKET
MIRRORED SURFACE
WAVE GUIDE END CAP- 3 PLACES - SEE DETAIL 1
WAVE GUIDE MOUNTED IN INSERT
ALUMINUM INSERT
MOUNT
LENS ADJUSTMENT
LASER BEAM
LENS
SWIVEL HOUSING
WAVE GUIDE
SECTION VIEW A
FIG. 7
A
TOP VIEW
FIG. 7A
SIDE VIEW
FIG. 7B
FRONT VIEW
FIG. 7C
END CAP BORE SAME AS I.D. BORE OF WAVE GUIDE
WAVE GUIDE END CAP
WAVE GUIDE WALL
DETAIL 1
FIG. 7D
DETAIL 2-SAME AS 1, BUT W/O END CAPS
FIG. 7E



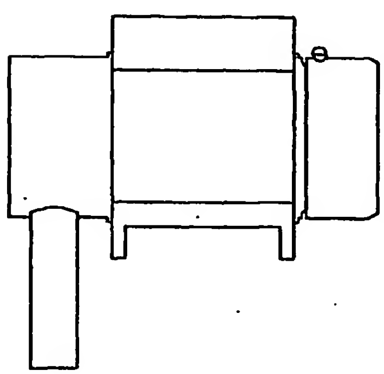
TOP VIEW
FIG. 8A



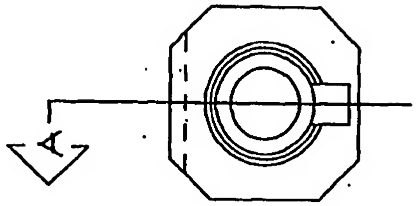
FRONT VIEW
FIG. 8C



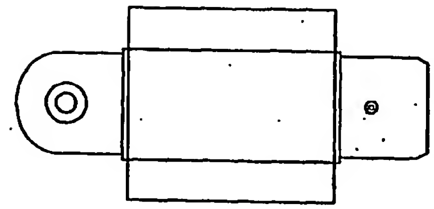
SECTION VIEW A
FIG. 8



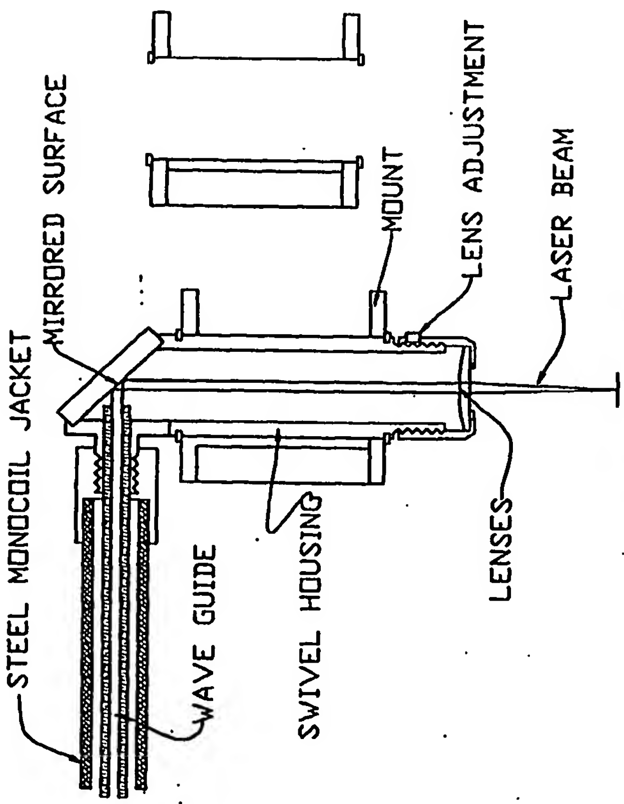
SIDE VIEW
FIG. 8B



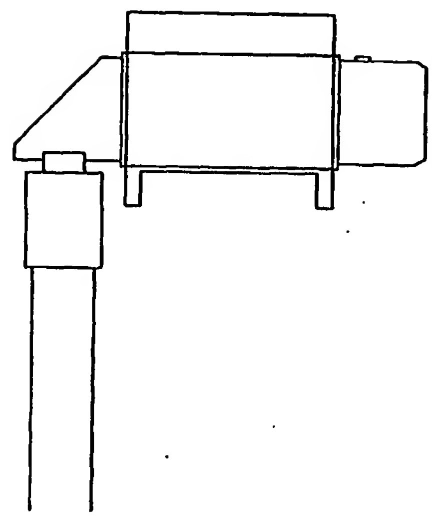
TOP VIEW
FIG. 9A



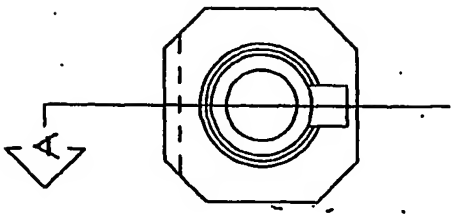
FRONT VIEW
FIG. 9C



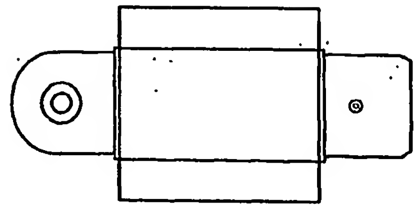
SECTION VIEW A
FIG. 9



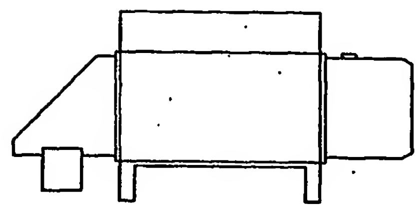
SIDE VIEW
FIG. 9B



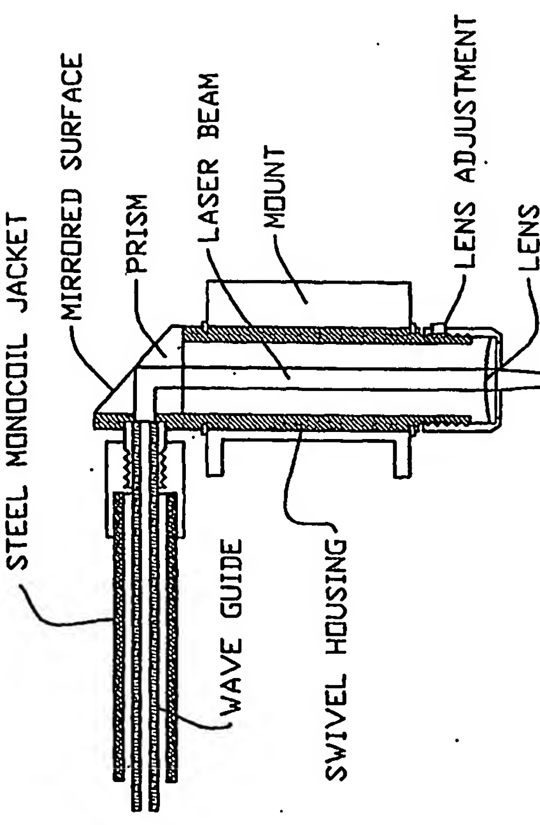
TOP VIEW
FIG. 10A



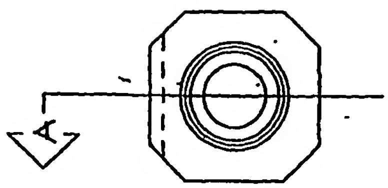
FRONT VIEW
FIG. 10C



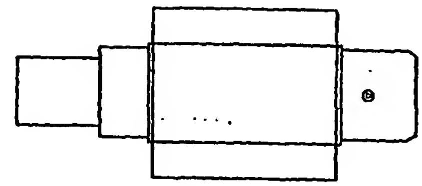
SIDE VIEW
FIG. 10B



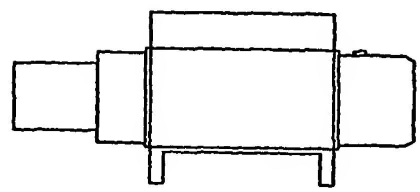
SECTION VIEW A
FIG. 10



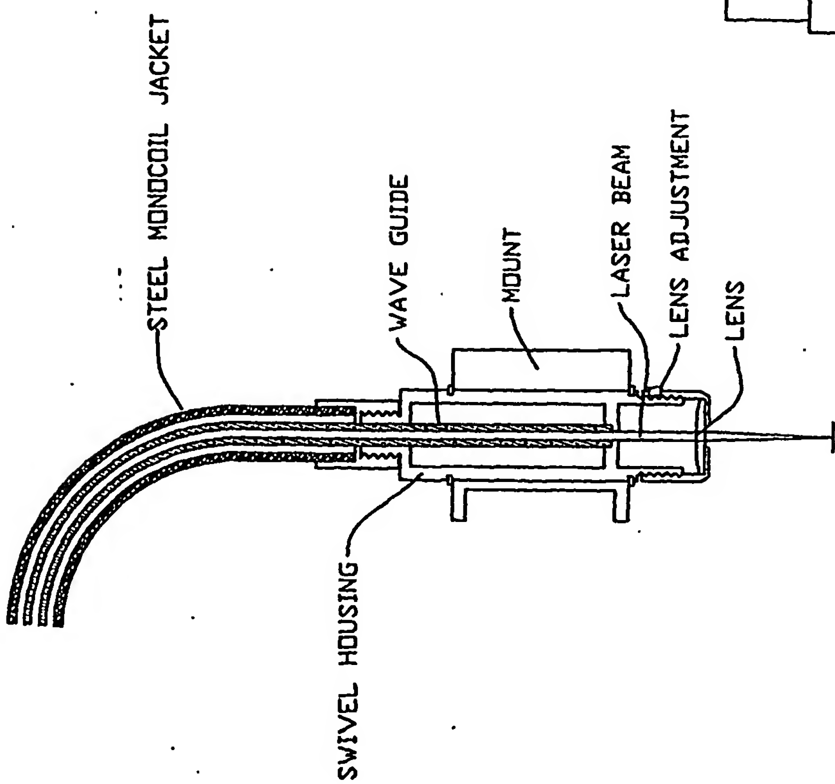
TOP VIEW
FIG. 11A



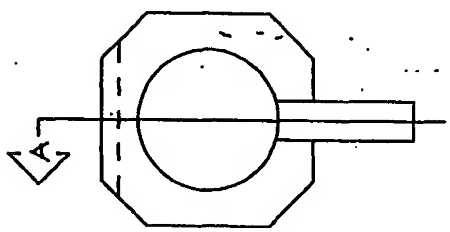
FRONT VIEW
FIG. 11C



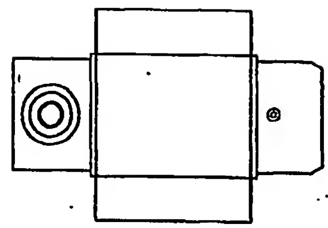
SIDE VIEW
FIG. 11B



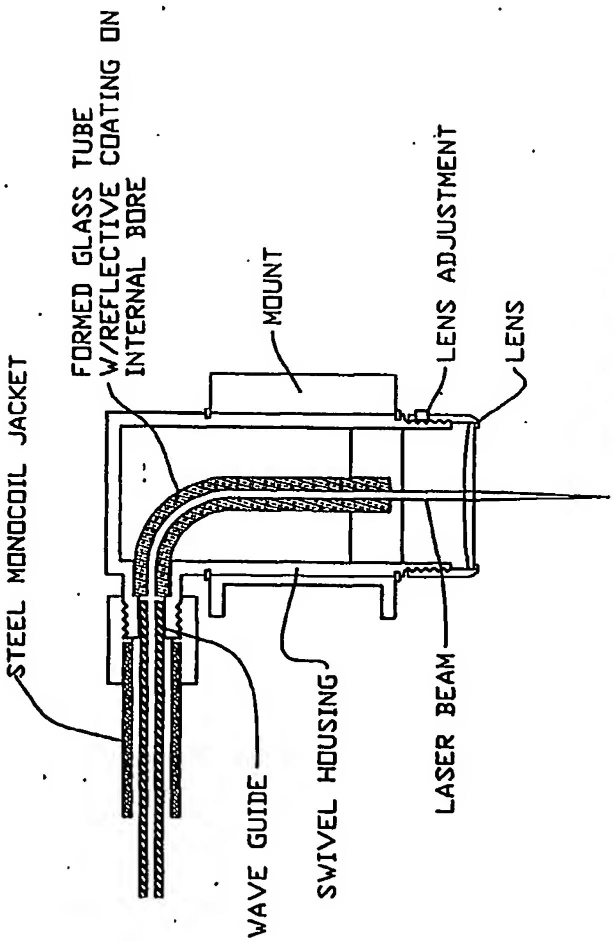
SECTION VIEW A
FIG. 11



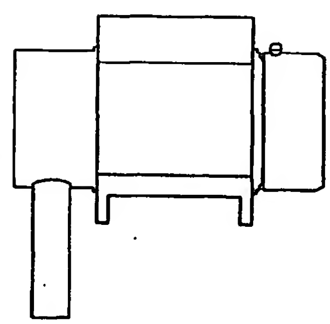
TOP VIEW
FIG. 12A



FRONT VIEW
FIG. 12C



SECTION VIEW A
FIG. 12



SIDE VIEW
FIG. 12B

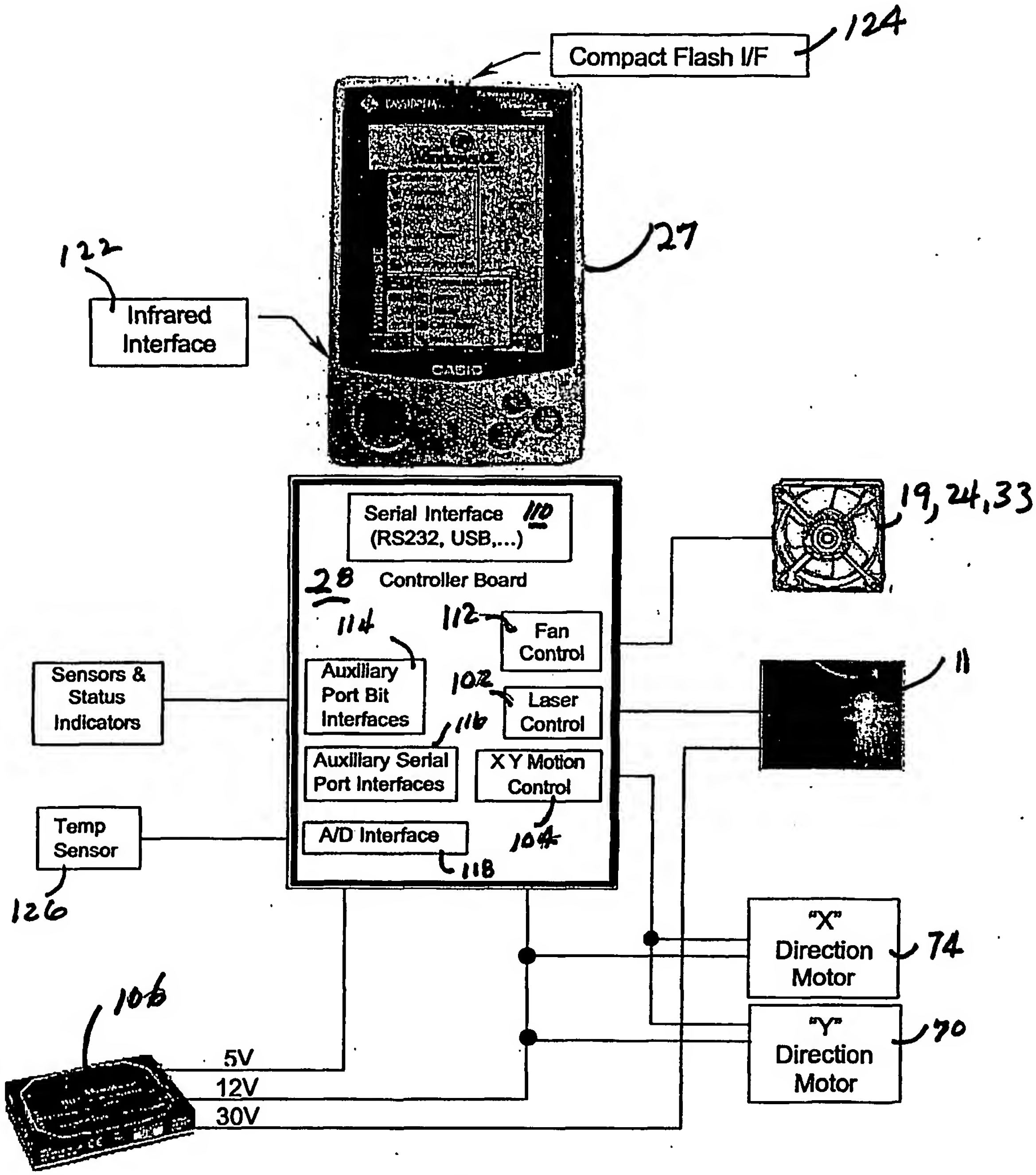

Compact Flash I/F
124
27
122
Infrared Interface
CASIO
Serial Interface (RS232, USB,...)
110
28
Controller Board
114
112
Fan Control
Auxiliary Port Bit Interfaces
102
Laser Control
116
Auxiliary Serial Port Interfaces
X Y Motion Control
A/D Interface
104
118
19,24,33
11
Sensors & Status Indicators
Temp Sensor
126
"X" Direction Motor
74
"Y" Direction Motor
70
106
5V
12V
30V

FIG. 14

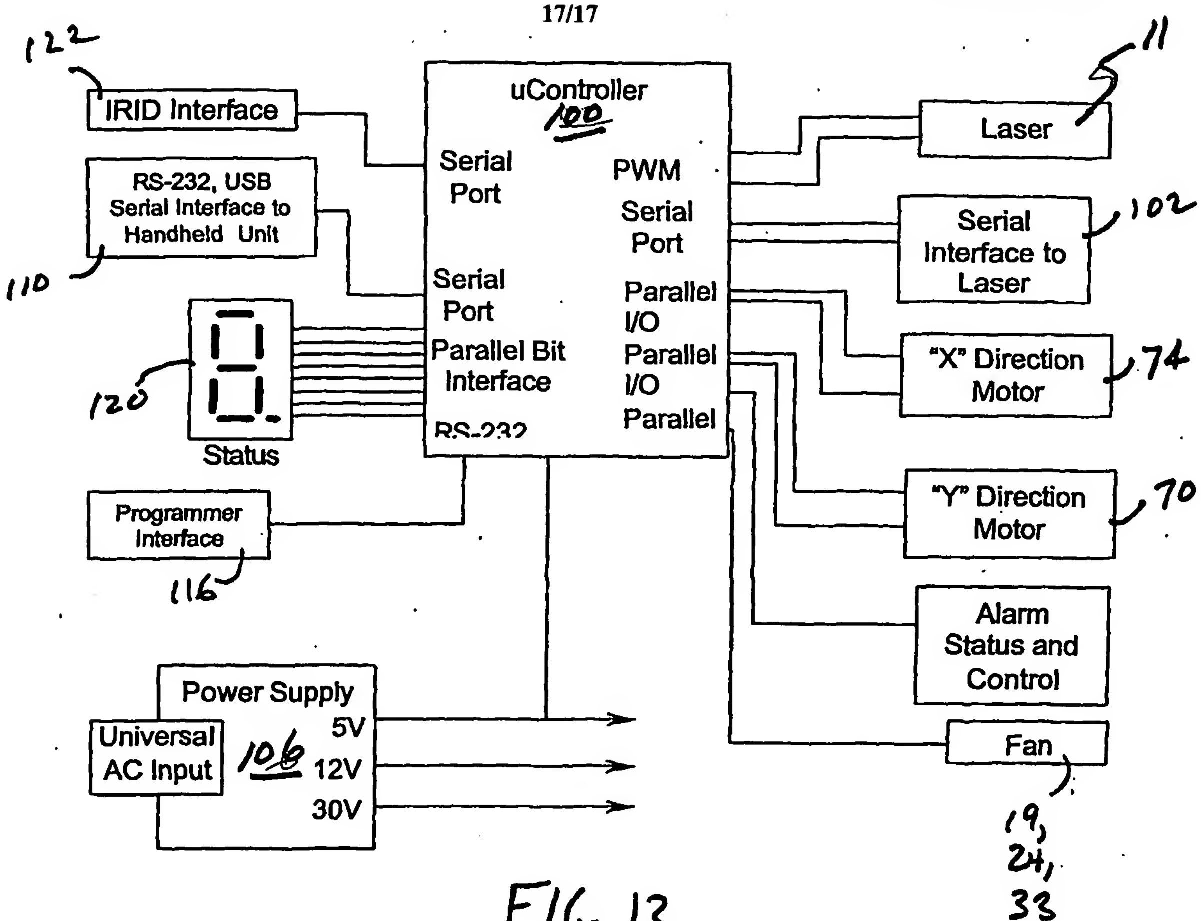

122
IRID Interface
RS-232, USB Serial Interface to Handheld Unit
110
120
Status
Programmer Interface
116
uController
100
Serial Port
Serial Port
Parallel Bit Interface
RS-232
PWM
Serial Port
Parallel I/O
Parallel I/O
Parallel
Laser
11
Serial Interface to Laser
102
"X" Direction Motor
74
"Y" Direction Motor
70
Alarm Status and Control
Fan
19, 24, 33
Power Supply
Universal AC Input
106
5V
12V
30V

FIG. 13

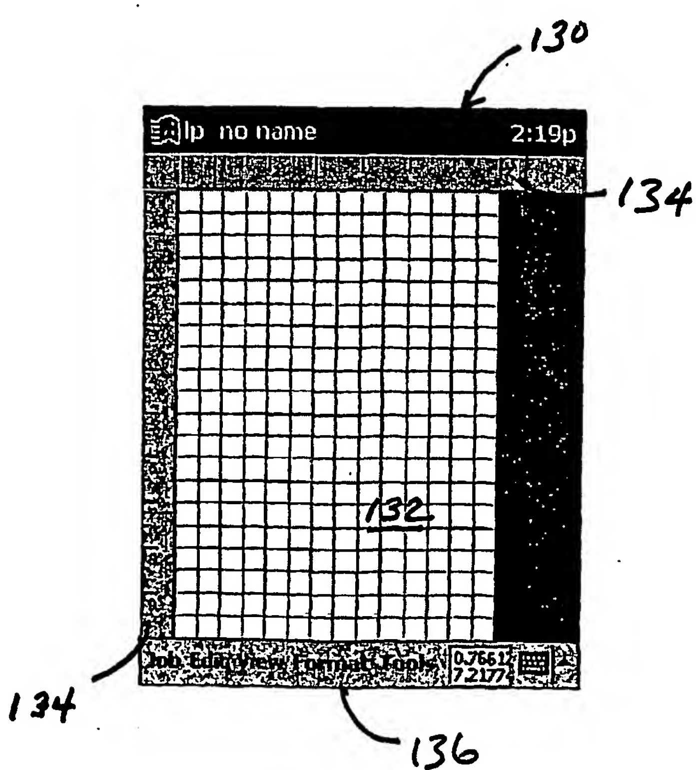

130
lp no name
2:19p
134
132
134
136

FIG. 15